RESEARCH ARTICLE

Transmission Control Protocol Performance Monitoring for Simulated Wired University Computer Network using OPNET

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ABSTRACT

Computer networks need protocols to govern all transmission and presentation processes. The transmission control protocol (TCP) is one of the most important protocols that have the compatibility to work with all types of computer networks, overcoming all architectural and operating system differences. Nowadays, networks depend on the TCP protocol to control data flow between all types of connected computers, whether it is client or server, over any type of media whether it is wired or wireless networks, for all network topologies. A simulation of a university campus network has been conducted to determine TCP protocol features; those features are taken into consideration as one of the most important network parameters. In all digital networks, the data transmission is not a continuous transmission – instead, it is a discreet transmission, presenting itself as packets. These packets transfer and propagate within the network between computers, and network nodes using the TCP protocol depending on the address, which is embedded in its header. TCP has a great influence on the network speed. The network simulator OPNET provides an easy way of campus design, predicting, and estimating the performance of networks in a university campus environment. In this research, wired connections reach all computer network users at fixed points to maintain higher Mbps and ensure reliable communications between all the campus network nodes, as well as to increase the overall network performance taking into account the future expansions for the university campus network design.

Keywords: Computer network design, Data traffic sent, Network delay, Network performance, Server hypertext transfer protocol, Throughput, Transmission control protocol, Voice over internet protocol

1. INTRODUCTION

Networks have grown rapidly over the past few decades and accelerating of accessing network resources. Congestion is an important factor in estimating the quality of a network. It also determines the dependability and sustainability of a network. Each computer network must use protocols within their design to govern the packet transferred. The protocols have many roles, which help in administrating the networks by the network operators, in addition to the standardized and default roles that contained in its default design. Transmission control protocol (TCP) (Hagen and Mullins (2013)) is the main internet protocol and it carries approximately 90% of internet traffic in diverse wireless and wired networks. TCP is a reliable end-to-end protocol because TCP offers reliable data transmission between two entities. TCP is an extensively used connection-oriented transport layer protocol that provides reliable data packet delivery over unreliable links. Using TCP, the data do not transfer as bits, but transfer as segments. Each segment contains many fields, some fields specified for addresses

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and some for source and destination nodes. There are many other fields specified for other tasks such as synchronization or checksum. Moreover, one of these fields is data field specified for the pure information that has been chopped or cut down into smaller pieces to be able to fit into the data size of the TCP protocol header data field before being sent from the sender (source); then, it gets sent over a media than to the intended destination (recipient). The Mbps does not express the pure data transferred over the network, the pure data (part of the message) or pure information portion is expressed by a network parameter called throughput. The goal of this simulation is to minimize the delay that takes place, the deadlocks that may happen along the route, and the dwindling that the data encounter at all nodes and branches as it travels across the entire network. The TCP features should be determined and monitored to maintain the network performance. In this paper, voice over internet protocol (VoIP) application features are also discussed on the university network that has been designed and simulated, as well as results obtained about data traffic sent and received in many sizes, bytes, bits, or packets. Furthermore, hardware components have been chosen carefully taking into account; the cost to make the network design more reliable and to achieve high network performance for all applications such as VoIP and hypertext transfer protocol (HTTP). Therefore, to make it available for each node in the network by providing high speed with less latency or delay and without any freeze, collisions or congestions reaching all the connected nodes of the network.

The number of hosting computers and users is rapidly growing across all the network types such as local area networks (LANs), metropolitan area networks, and the internet as a whole, with very wide variety as Wi-Fi and Wi-Max end points for wireless system networks, and fiber-optic cable for the wired users. In addition to that, the applications of modern endpoints such as up to date smartphones and modern computers require much higher data transfer and throughput than ever and they are on continues rise; thus, computer network designer must take that into consideration by installing fast and intelligent devices to support this growing challenge and fulfilling the demand. In this simulation, results are obtained for two cases when firewall installed and when no firewall is installed on the network. For network simulation of OPNET, there are many configurations to make the network simulation work. Results are shown from the simulation that the VoIP service users can reach approximately 300 computers at the same time if the network uses IP Telephony. Thus, the VoIP service can be used instead of the PSTN public system telephony network infrastructure for better quality and lower cost.

The remainder of this paper is organized as follows: A background about TCP protocol and its reliability compared to other transport layer protocols is visited in Section II. In Section III, the new design is proposed for the university campus and illustrated. The specification of the network devices is laid out and justified in Section IV. In Section V, the choices of the physical layer are justified, and future expansion is considered. In Section VI, the simulation is applied for the period of 23 min and the results are obtained. The paper is concluded in Section VII.

2. LITERATURE REVIEW OR BACKGROUND

Evangelista et al., 2014, did a simulation on the performance of TCP and UDP and did a comparative analysis between these protocols as they are the most common transport layer protocols. They implemented and designed the network using OPNET and demonstrated the results of the differences between them in client-server network. It showed that TCP is more reliable and provides congestion control services.

There was also a study conducted by (Le et al., 2009) of TCP throughput on network using OPNET simulator. In this work, the effect of the size of flow control window was examined on the throughput of a connection. This was done using simulation parameters such as file size (bytes), packet latency time (s), and interrequest time (s). The two most important factors while transferring data with TCP are round trip latency and window size. Their finding showed that the larger window size was the higher data it received even though both servers waited the same amount of time between acknowledgments, more packets were transmitted, hence, completing the downloaded quicker. Pawlikowski et al., 2002, designed a simulation through OPNET for Mosul University. Three applications were added to test the network design. These applications were file transfer protocol (FTP), HTTP, and VoIP. The results showed that the proposed model had a positive efficiency on designing and managing the targeted network and could be used to view the data flow in it. Dong et al., 2008, presented a design and implementation of hybrid network for different IP routing protocols in low load campus network. In this network model, generic LAN and WLAN models were used. In this work, a simulated environment was created where many applications were used at the same time and their mutual effects thereof. This model was tested against various types of applications (FTP, ATM, and remote login) in hybrid networks. Two routing protocols Routing Information Protocol (RIP) and interior gateway routing protocol were used to check the performance of hybrid network for different applications. This OPNET simulation showed the impact of IP routing protocol for hybrid networks for different types of applications. The authors (Kotz and Essein, 2002) designed a computer network infrastructure to support various activities both administrative and academic. The infrastructure that was built covered all areas of the campus. With an increasing range of services, the Tarumanagara University needed to enhance local area network to accommodate their needs. The new network infrastructure that was built had to guarantee the quality of services, reliability, scalability, and supporting future expansions. The network design was the most important and critical part of system development that comes before implementation. Analyses of user and network requirements were done before the design of the network. The building block components of the hierarchical structure network were the core layer, the distribution layer, and the access layer. The core layer was designed with redundant device using Layer 3 switch, the distribution layer at each building was designed with using Layer 3 switch as well, and the access layer was designed using Layer 2 switch. Jaswal and Kuldeep Vats conducted a simulation and an evaluation of three different sized networks (small, medium, and large) was carried out.

In this paper, we are using the modeler to study networks with 15, 25, and 40 mobile workstations. In each network, a group of five WiMAX workstations connects and call each other through one WiMAX base stations during 1000 s. Performance of the parameters that indicate the quality of services such as initial ranging activity, delay, total transmission power, and PHY path loss has been studied.

Adhicandra, 2010, evaluated the performance of integrated network with the help of the following scenario, the simulation was conducted using different applications as follows: FTP, audio, and video. The results were compiled and compared based on various parameters, which included, delay, traffic sent and received, load, MOS value, jitter …. The simulation results showed that, when applications were changed, the parameters changed as well, for example, delay for FTP. Similarly, the traffic and response time for each varied. Nassar et al. as stated in (Le T., Kuthethoor, et al, 2009) studied the firewall principles and various types. They reported the experimental results of the simulation of application proxy firewall using OPNET simulator. From the results, they found that the firewall deployment had some benefits and drawbacks in respect to network performance. Some of firewall benefits were the improvement of link utilization and throughput. The main drawback of applying firewall (application proxy) was the delay produced due to the full inspection process. The parallel firewalls technique used in this paper was not only solving some problems of traditional firewalls such as delay and average response time of HTTP server but also it improved most of the network performance parameters. Finally, the parallel firewall was cost effective from the performance point of view, and the firewall by itself could not cover all the security requirements of modern networks, but it could be considered as the first step toward a secure network solution (Nassar et al., 2010).

Reviewing all of these literatures implied that there is a need to design a network and then simulate it using OPNET as it was used for this paper. Figure 1 shows the main modular design that is to be implemented for simulation. From the result obtained, an efficient analysis can lead into more efficient and reliable design that includes the media used, switch categories, transmission technologies, and protocol types. Ali et al., 2009, the emphasis is on the importance of firewalls in securing network communications and resources. Still, more processing of networked information may contribute to performance degradation of networks. Hence, it is important that as firewalls are examined in terms of their contributions to network security, they should also be investigated in terms of their effectiveness in web protection. They implemented various scenarios incorporating firewalls and analyzed them in regard to corresponding effects on the network performance. For this, simulation models were created and implemented on OPNET for calculating network performance with and without firewalls. Their findings showed that security and improved performance are inversely proportional and cannot be 100% achieved in every scenario, especially in the current cyber world as threats are becoming more and more substantial. For further information, readers are encouraged to read (Barznji et al., 2018; Rashid and Barznji, 2018).

3. PROPOSED DESIGN OF THE NETWORK FOR THE UNIVERSITY CAMPUS

This research is dependent on OPNET to design a computer network for university campus to measure computer performance parameters. For measuring the parameters of the network topology and connected devices and to configure service values to determine which case is performing better. The result shows which parameters (throughput and delay) are going to increase or decrease. The network is connected as the following; a server is connected to the router through a switch and configured to support the applications which need to work in the network simulated environment. The main switch connects the smaller networks that represent colleges together. Where switches fixed in the colleges used to connect the computers in each college. A *"100BaseT" "cat6"* twisted pair cable is used to link the network components in all the sector of the network except the links between the college switches and the main switch. The *"1000BaseT" "cat6"* is sufficient to fit the bitstream demand required by each one of the users; this cable reaches the end user or end computer. Fiber-optic cable is also used to link the college switches to the main switch. This provides two benefits to the whole network. The first one is that high bandwidth is achieved due to the fiber-optic specifications while for the second one, longer distance is achieved. The use of *"1000BaseT" "cat6"* will not cause a bottleneck because the bandwidth needed in the entire college network is fulfilled by the speed of 1000 Mbps. The proposed design of the network for the university campus can be seen in Figure 2.

4. CAMPUS NETWORK INTERCONNECTION

The network interconnection consists of 17 switches, each with 64 ports or RJ 45, suited to connect using STP (shielded twisted pair) cables. Each switch is placed in its specified location (college) to distribute services to the college using STP cable (*100BaseT*).

Furthermore, all these switches are connected via 1000BaseX fiber-optic cable with the core switch located at the center of the university campus. This represents the backbone of the network. Six core fiber-optic cables (single mode KSA) are connecting the college switches to the core switch. The core switch, in turn, is connected to a server to obtain some of the internet services such as VoIP, e-mail, and HTTP. The core switch is also connected to a router to isolate the university network from the outside cloud which provides the internet connection to the network. To increase the security, firewall is placed between the cloud and the router. Moreover, the firewall is used to protect the entire network computers from the intruders and the hackers. The server is placed behind the firewall purely for protecting the services from intruders. The capability of this design to plug in wireless services is there and can be incorporated by simply replacing the college switches to wireless routers to propagate wireless services. Table 1 shows the used components in this project.

The network is configured to produce many services such as HTTP, VoIP, packet transferred per second, and delay in the profile definition. Furthermore, each computer should be configured to simulate that service and then get the results in the end.

5. THE COLLEGE NETWORK

The computer network is spread over an area of 3000 m^2; the colleges are distributed around the central building of the university. The presidency location assumed to be as one of the college networks [Figures 1 and 2]. In addition to this, there are 16 colleges, each considered as a network. This represents the university's hierarchical configurations.

Furthermore, it is noticed that each college switch is of 900 m distance from the central switch, this fulfills the cable media specification requirement of the physical layer. Fiber-optic cables 1000BaseX are able to connect computers distant from one another by up to 950 m.

The college networks consist of 20 computers distributed around each college location. The college computers are connected through STP cables interconnecting each computer to a central switch of 64 port switch ready for future expansion. All the college switches are connected to the main switch by a fiber-optic cable 1000BaseX. This one is connected to the main router. The main router profile definition is configured by the application that is needed for the simulation in this project. This application should be configured on each node (PC); otherwise, the PCs cannot get the benefit from that specific application configuration. Furthermore, the server should be configured to get these application profiles. Addresses can be configured on all devices of Layer 3 (network). In this project, IP addresses are configured on each device of the network.

6. SIMULATION AND RESULTS

The simulation was applied for an interval of 23 min which should be sufficient for all the network components and devices to get stable, after all the components having been installed on each device. Figure 3 shows the object statistics campus network performance task processing time measured in seconds. It can be clearly seen that until the 4th s, there was not any activity. However, after the 4th s results began to emerge reaching 0.0091 s and stabilizing product at 0.0028 s and 0.001 s for minimum value.

The TCP active connections' count for server as shown in Figure 4 starts after the same interval and reaches 93 connections at the beginning for the overall network, then gradually decreases reaching 20 connections.

In Figure 5, it shows object statistics campus network server; the TCP delay starts at 0.0016 s then stabilizes at 0.00042 s.

Then, Figure 6 shows object statistics campus network server TCP load, measured in bytes, and similar to all of the previous curves, it starts after the 4th min reaching 2.2 MB the firewall is being used, and 2 MB when firewall is not used, and reaching 0.3 MB as a minimum value.

After that, Figure 7 shows the TCP load in byte per second. This curve shows insignificant behavior before the 4th min then after the 4th min it picks up and reaches 37 KB/s. When the firewall is used, it stabilizes and the value decreases to reach 22.5 KB/s.

When TCP load for the server measured in as shown in Figure 8 reaches 700 packets; then, it decreases until it reaches 180 packets as it stabilizes.

The object statistics campus network server TCP load packet/sec reaches 12 packets/s as a stable value shown in Figure 9.

Figure 10, on the other hand, shows object statistics campus network server TCP segment delay/second in this figure no

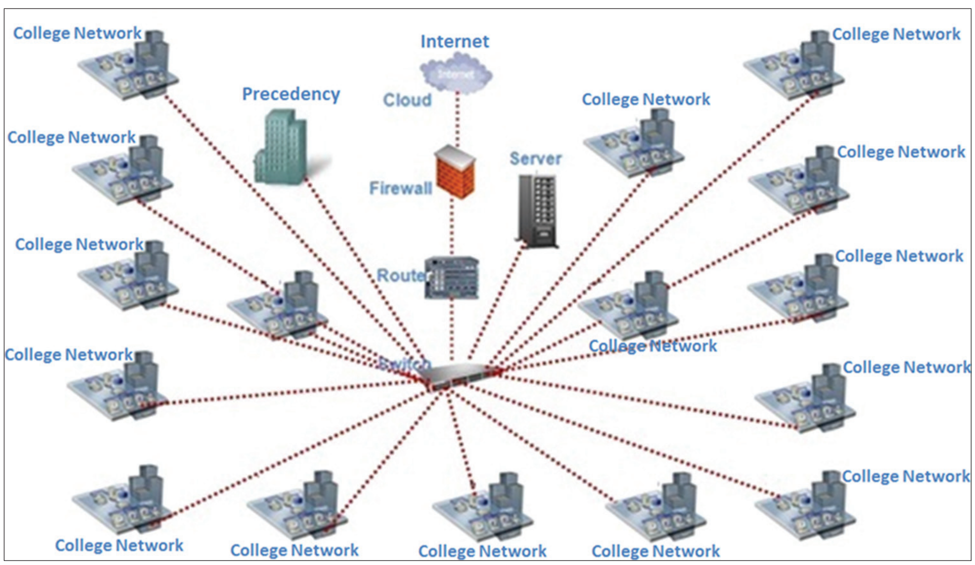

Figure 1. Symbolic network main design for the university campus

Table 1: The components that are used in the project

Components	Description	Pieces (Qt.)
1 – Computer	Personal computers	342
2 – Core switch	Ethernet connections at the CISCO catalyst switch 6509 specified data rate (10, 100, and 1000 Mbps)	20
3 – Workstation	Personal computers with Ethernet LAN card each of 100 Mbps and RJ-45 termination connected with 64 switch by 100Base100 STP cat6	240
4 – Router	The Cisco device (Cisco 7507) ethernet to ethernet, FDDI to FDDI,	1
5 – Firewall	Ethernet connection	1
6 – IP cloud	NK_CKP_Firewall_8e_adv eth64_sl64_atm16_fr16_adv	1
7 – 1000BaseX fiber-optic cable	Sufficient for 1000 m and speed of 1000 Mbps 4 twisted paired single wires	5000 m
8 – 100Base100 STP cat6	Sufficient for 100 m and speed of 100 Mbps 4 Twisted paired STP	24 rolls each with 305 m
9 – 16-port Switch	Cisco2948 data rate (10, 100, and 1000 Mbps)	2

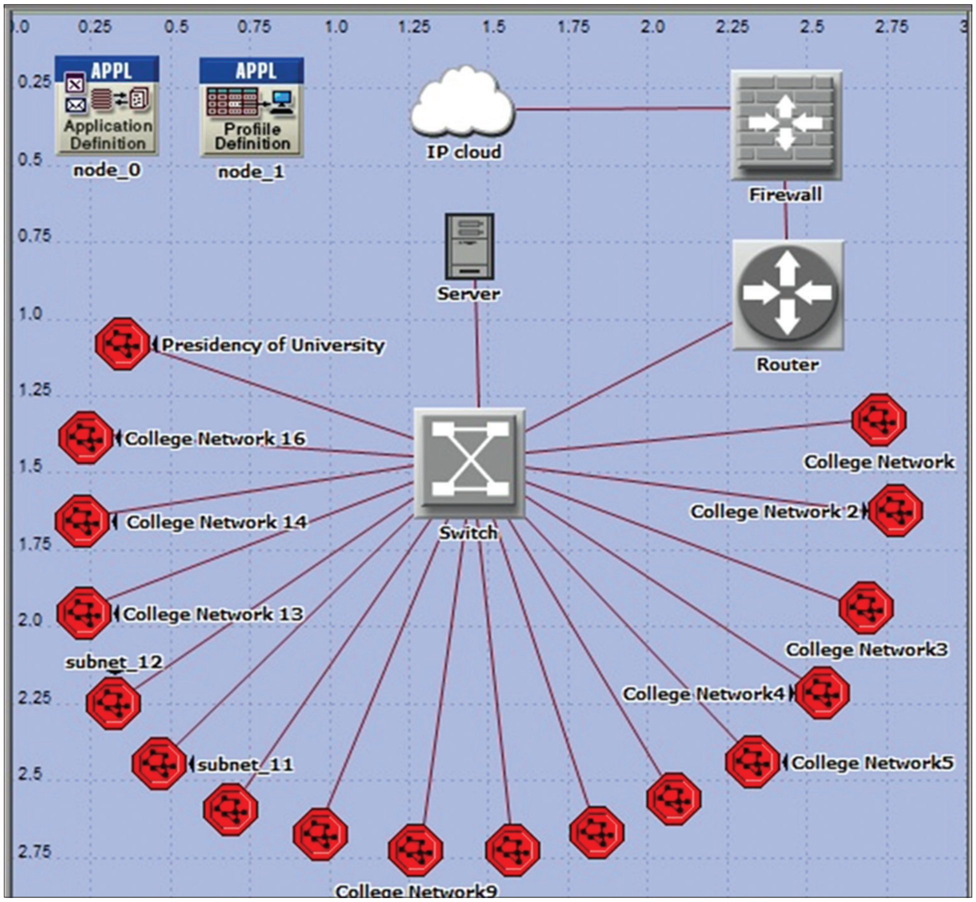

Figure 2. Network main design for the university campus

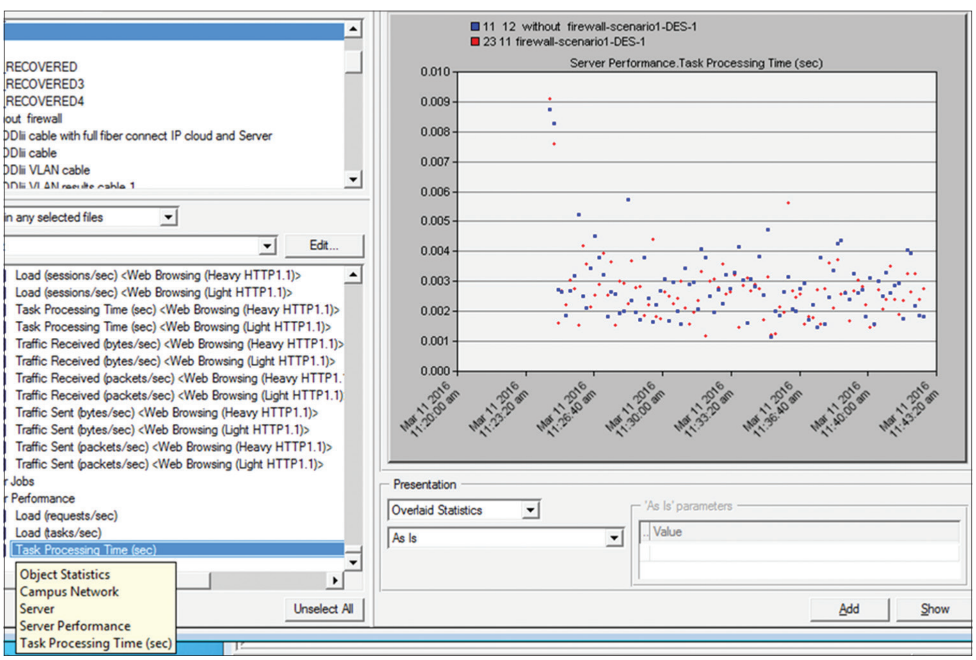

Figure 3. Object statistics campus network server performance task processing time/s

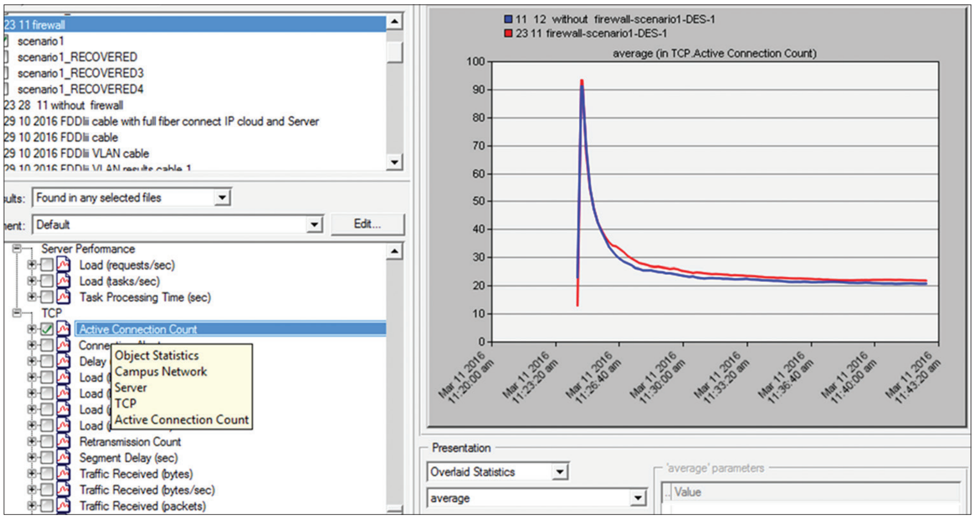

Figure 4. Object statistics campus network server transmission control protocol active connection count

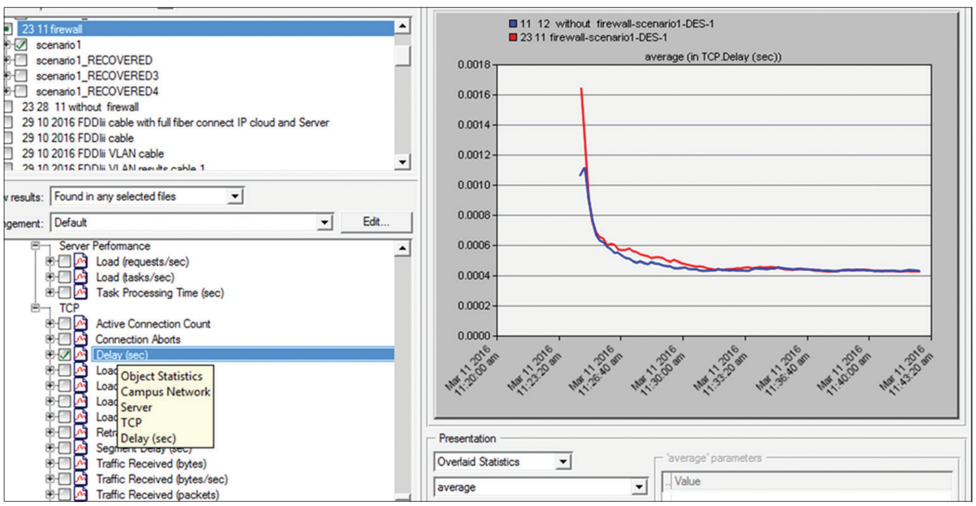

Figure 5. Object statistics campus network server transmission control protocol delay/s

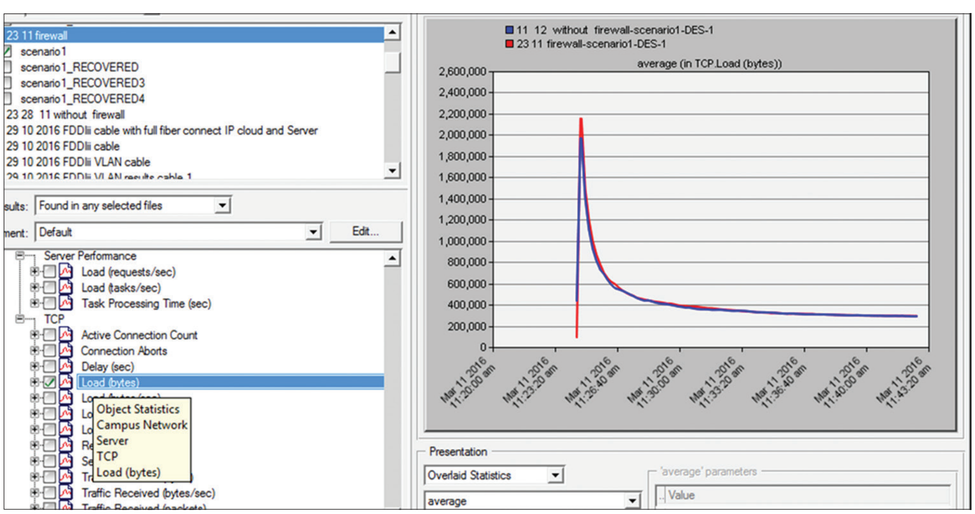

Figure 6. Object statistics campus network server transmission control protocol load in byte

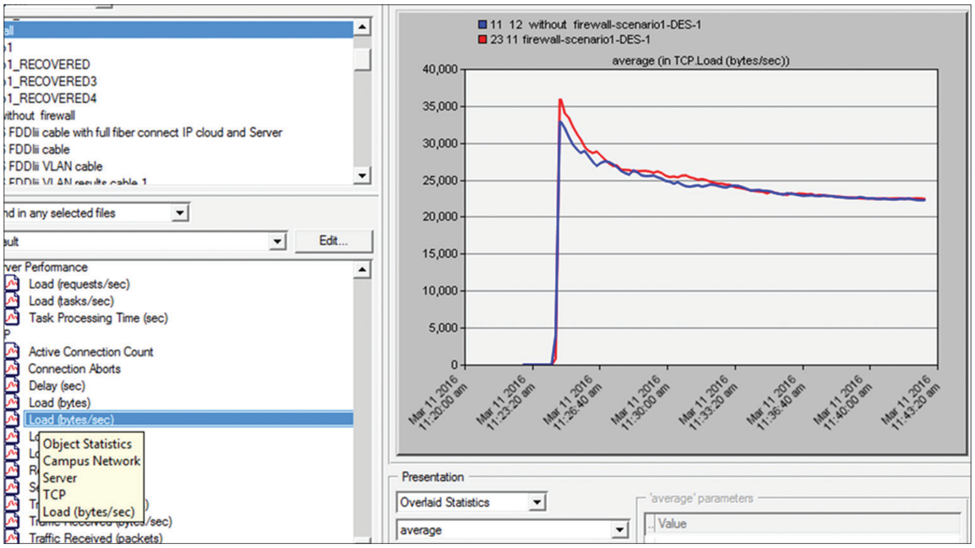

Figure 7. Object statistics campus network server transmission control protocol load B/s

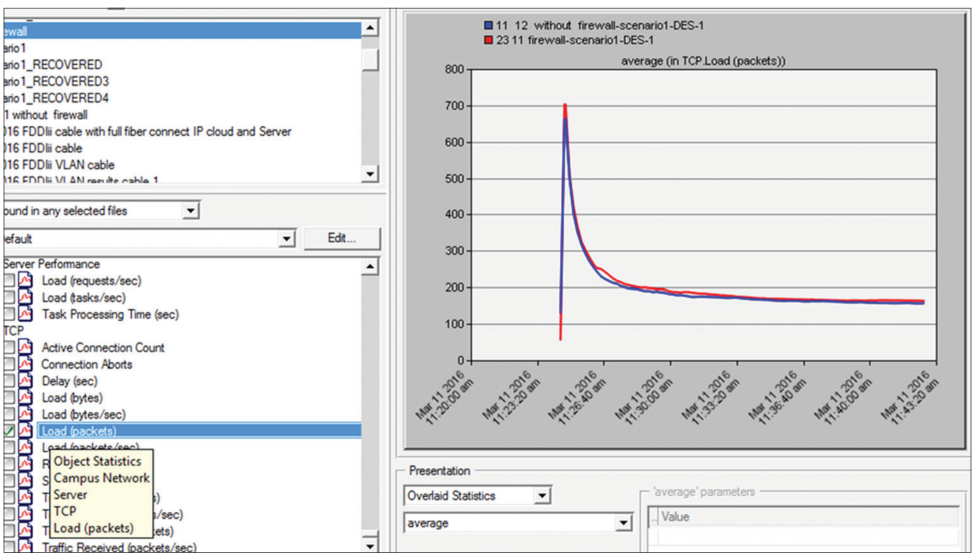

Figure 8. Object statistics campus network server transmission control protocol load packets

indication appears till the 4th s and starts by 0.00037 s then after 10 min it stabilizes at 0.000175 s.

Figure 11 shows the object statistics campus network server TCP traffic received measured in bytes, the maximum value reaches 1.7 MB then stabilizes at 200 KB which is sufficient to serve a large number of users. This decline in data traffic which is shown in many figures in this paper is due to the huge demand of data transfer before the configuration and addressing is achieved. Then, after this ends, the data transfer returns to decline at a stable rate as the demand decreases.

Figure 12 shows the object statistics campus network server TCP traffic received in Bps which reaches 25 KB then decreases after 20 min to 14 KB.

Based on the results obtained from this simulation on the proposed design for this particular university, as well as choosing the proper components, media, and physically implementing the application according to this design. The results showed that, if we install this design to the exact specifications, we will get a good and sufficient bit and packet stream transferred among all the network nodes with a good performance.

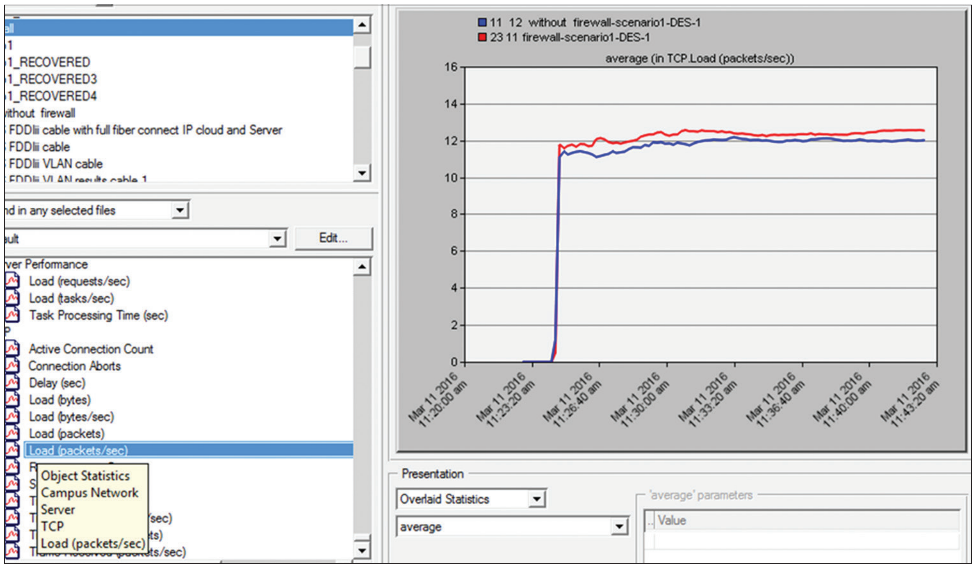

Figure 9. Object statistics campus network server transmission control protocol load packet/sec

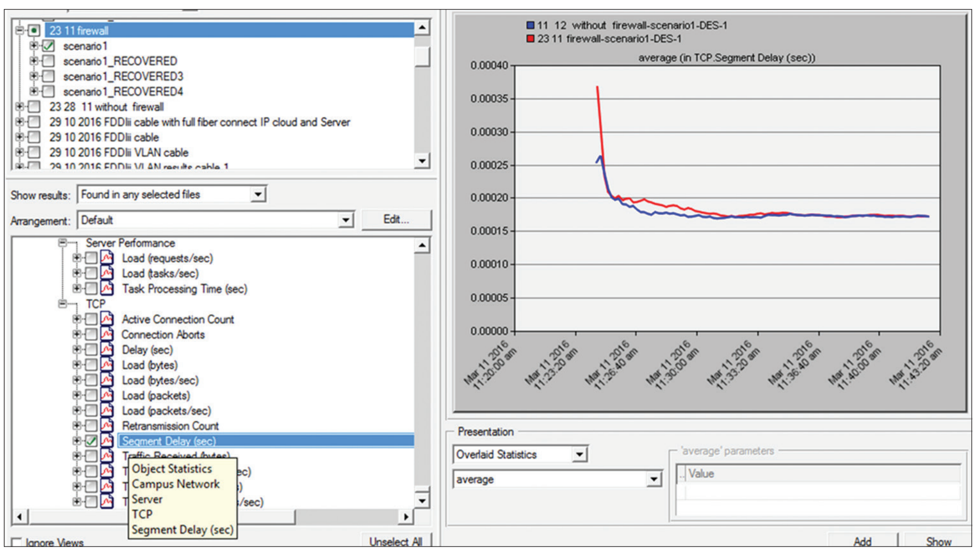

Figure 10. Object statistics campus network server transmission control protocol segment delay/s

7. CONCLUSION

In this paper, a network for Salahaddin University new campus was designed. OPNET was used to conduct the simulation and test the proposed design considering TCP as its transport layer protocol. The performance of the network was investigated for its quality of service criteria such as delay and loss. The proposed design provided requirements for hardware that can facilitate required services such as HTTP, VoIP, and e-mail. Other performance measures on the server side were studied to locate necessary resources for running the services. The number of TCP active sessions and delay was among the targeted parameters. The results showed that the network design with proposed hardware ensures the provision of the services while maintaining the quality of services such as delay and throughput. Future work will consider performance issues that may arise during the implementation.

Fast media should be used in this design to connect devices to give a sufficient Mbps and throughput to the university users such as students, lecturers, and administration staff. In general, wired computer networks provide more secure, high speed, and more reliable connectivity.

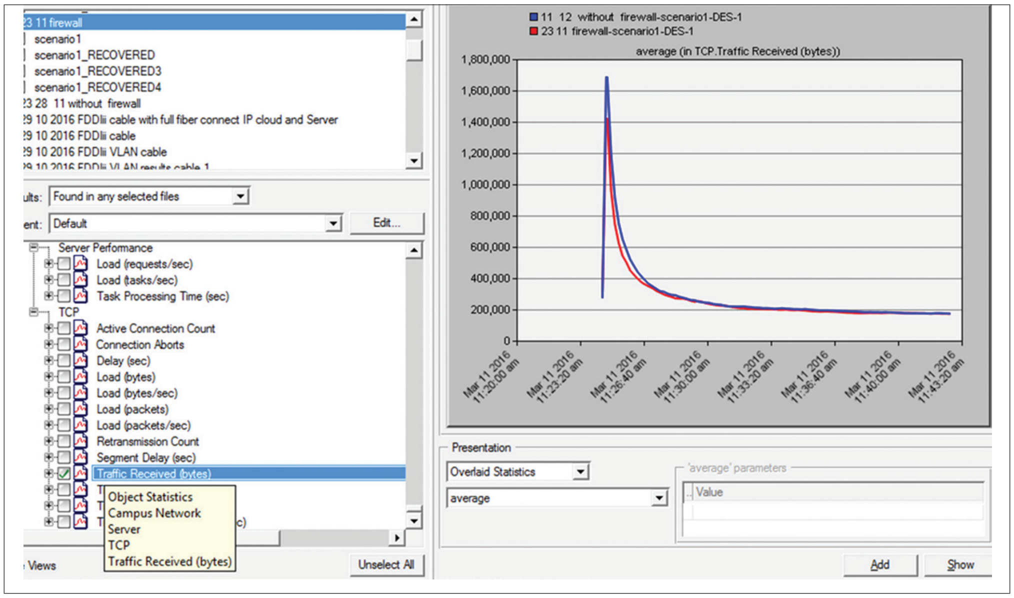

Figure 11. Object statistics campus network server transmission control protocol traffic received in byte/sec

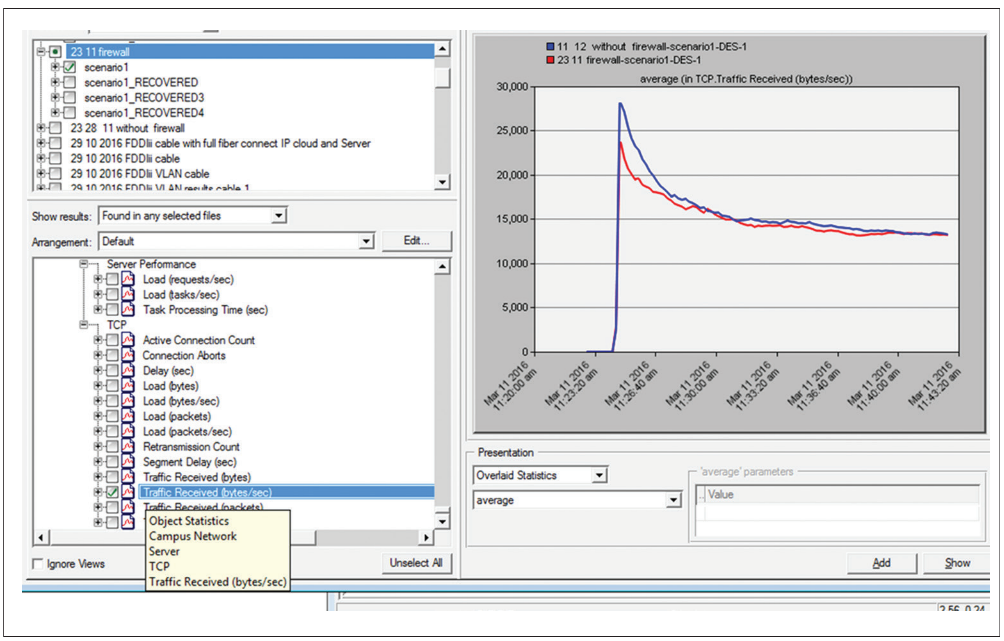

Figure 12. Object statistics campus network server transmission control protocol traffic received (B/s)

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